Power Reduction using LongRun2 in Transmeta's Efficeon Processor

Spring Processor Forum Presentation

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and the Transmeta LongRun2 Team

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LongRun2 Technologies

Transmeta CORPORATION

Agenda

Addressing Power and Leakage Challenges:

- Improve specs, improve yield and ship 100% of parts

Case Studies of LongRun2 Benefits:

- Reducing worst case power in Efficeon
- Increasing worst case MHz in Efficeon

Study 1: LongRun2 power reductions for 1.5 GHz operation

Study 2: LongRun2 power reductions for 700 MHz operation

Study 3: LongRun2 MHz improvements with a 4 watt power limit

Conclusions

Power and Leakage Challenges

The "Leakage" problem is growing as transistors shrink

- As technology scales down, Vt variation and leakage both increase

Leakage is a larger fraction of power hence variation matters more:

- Lower Vdd requires lower Vt to maintain performance
- Lower Vt has more leakage, but higher performance
- Higher Vt has less leakage, but lower performance
- Vt and leakage also vary with changes in temperature and Vdd
- Result is that power and frequency can vary over a large range

From the best part to the worst part across a large distribution:

- Power may vary by ~3x
- MHz may vary by ~1.5x

LongRun2 Technologies can dynamically adjust Vdd and Vt to

- Reduce worst case power at a given MHz, or
- Increase worst case MHz within a given power limit
- Reduce variation and get as close to 100% yield as possible

Transmeta's LongRun2 Technologies

In 2000 Transmeta introduced LongRun with:

- Dynamic MHz and Voltage
- Single and later multiple MHz / Vdd tables

In 2003 Transmeta introduced LongRun2 with:

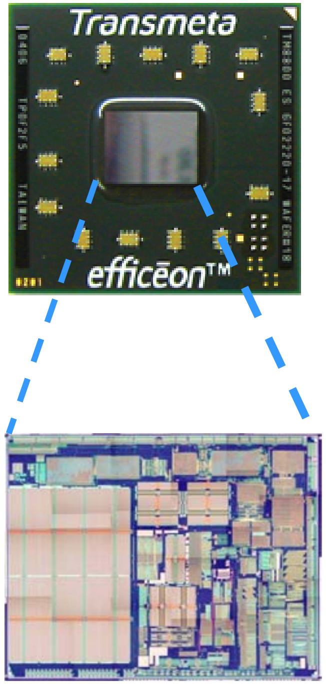
- All the original LongRun techniques and
- Dynamic Vt Control and other power reducing technologies

LongRun2 Vt Control provides a practical new approach to body bias

- Proprietary approach can be implemented in standard bulk CMOS
- Improves transistor body voltage distribution
- Adds capacitance that can reduce body contact noise
- Adds capacitance that can reduce power/ground noise
- Avoids bias voltage distribution in metal layers
  - Traditional body bias may increase chip area 3 - 5%
  - LongRun2 body bias does not increase chip area or change layout
- LongRun2 body bias can be easily retrofitted into existing designs

Case Study: LongRun2 in Transmeta Efficeon Microprocessor

21 mm x 21 mm package



65 mm^2 die size

High Performance x86 Compatible Processor

- 1-2 GHz Typical Operation
- 85 Million 90nm Transistors
- 8-Issue VLIW Hardware Architecture
- 1 MByte L2 Cache
- DDR Memory Controller
- AGP Graphics Controller
- HyperTransport I/O
- Flash Memory Controller
- 5 bits/pins of Voltage ID

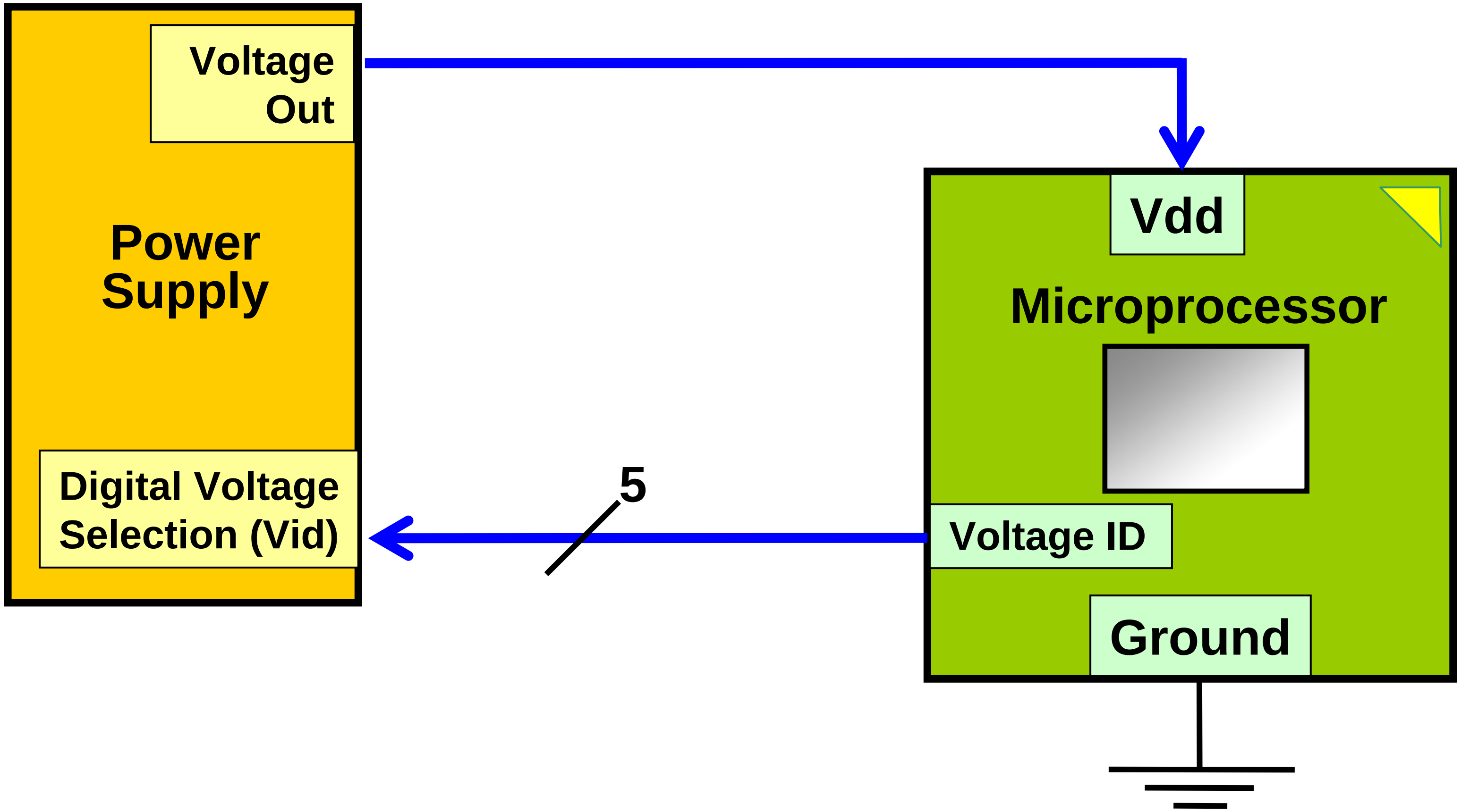
The following measurements are based on:

- Efficeon with LongRun2 Vt Control and Voltage ID Capability
- Fabricated in Fujitsu 300mm 90nm bulk CMOS in Mie, Japan
- Sample set: 202 parts measured on production tester at 50°C, 0.7V Vmin
- MHz and core power data is presented without guard banding

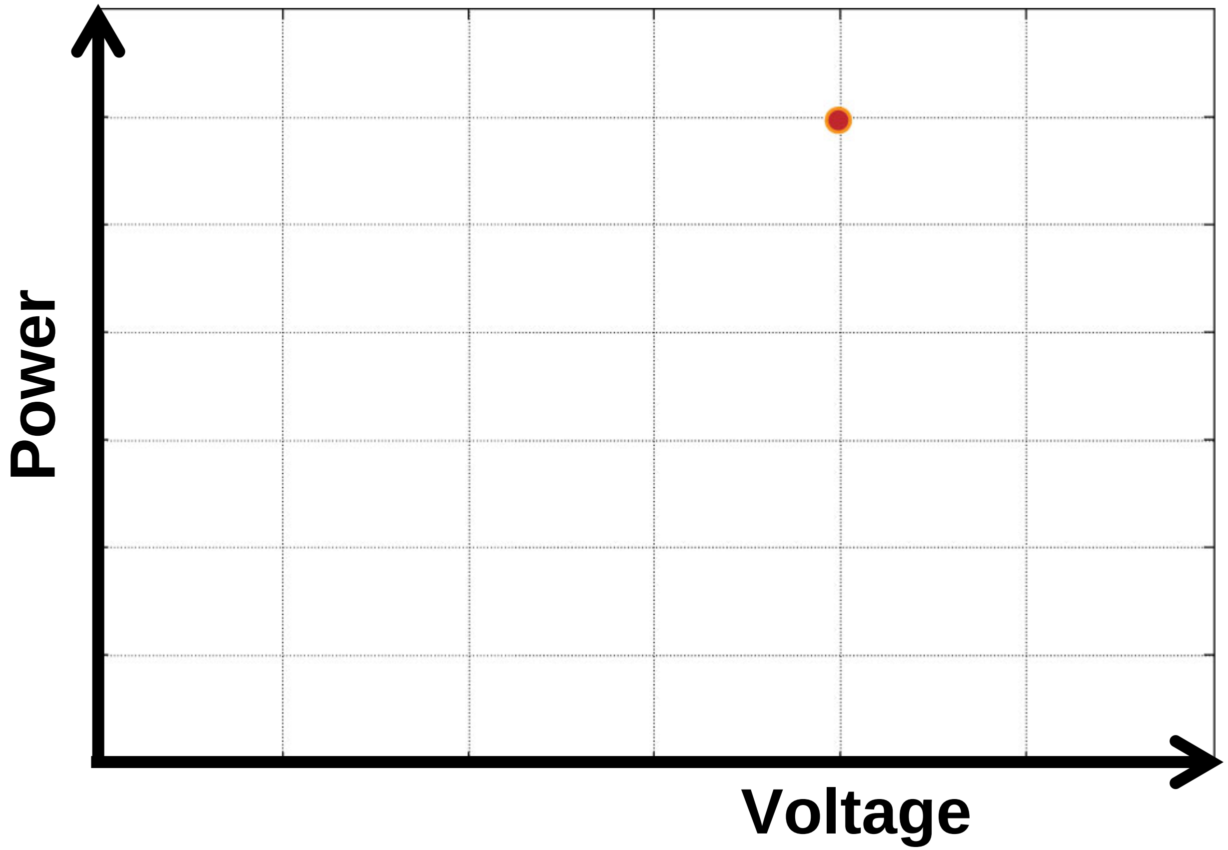
Vdd Control is Key to Power Reduction

Power = Dynamic Power + Leakage Power

$$\text{Power} = C_{effective} \times Vdd^2 \times MHz + Vdd \times I_{Leakage}$$

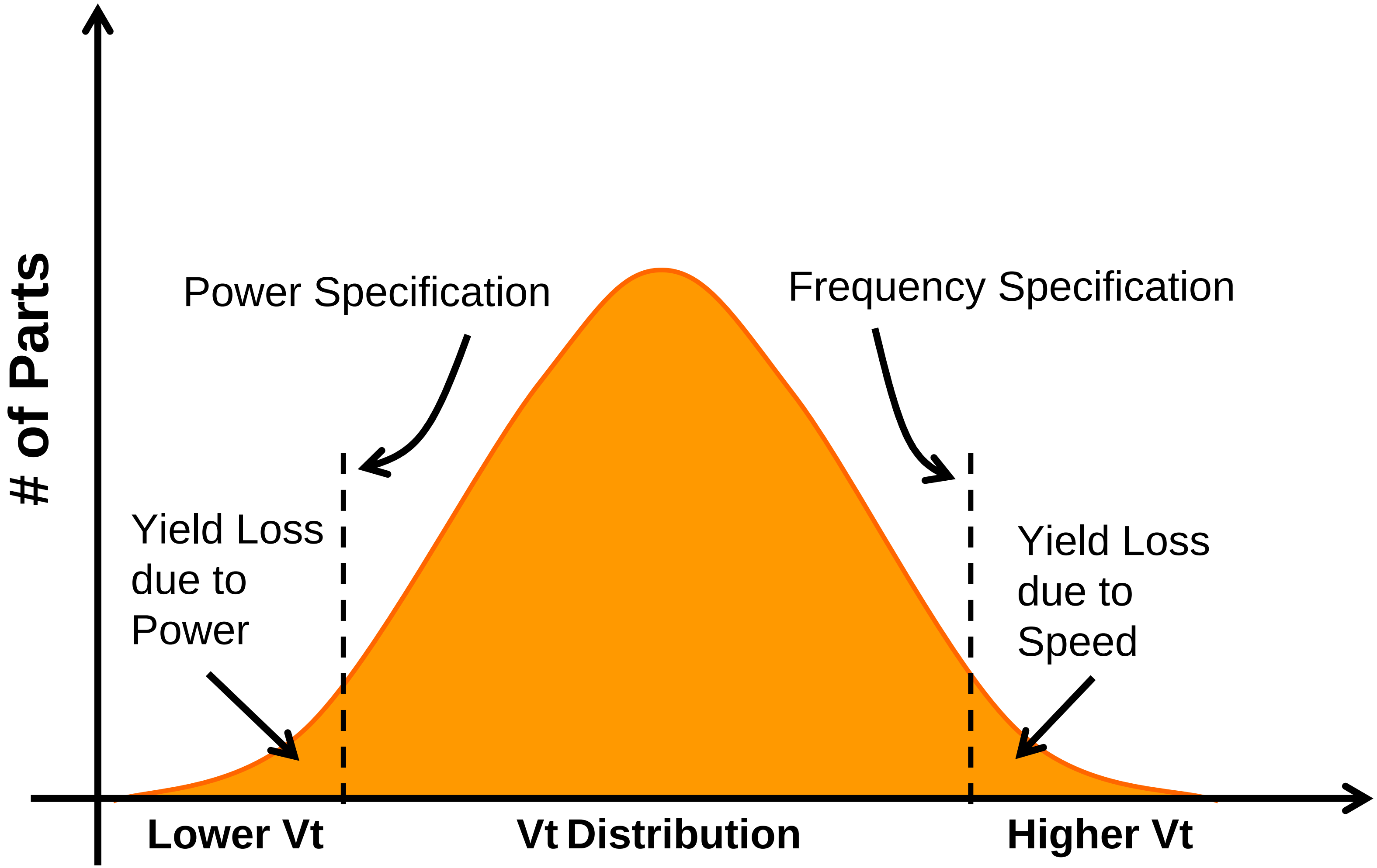


Single Fixed Vdd – “The good old days”



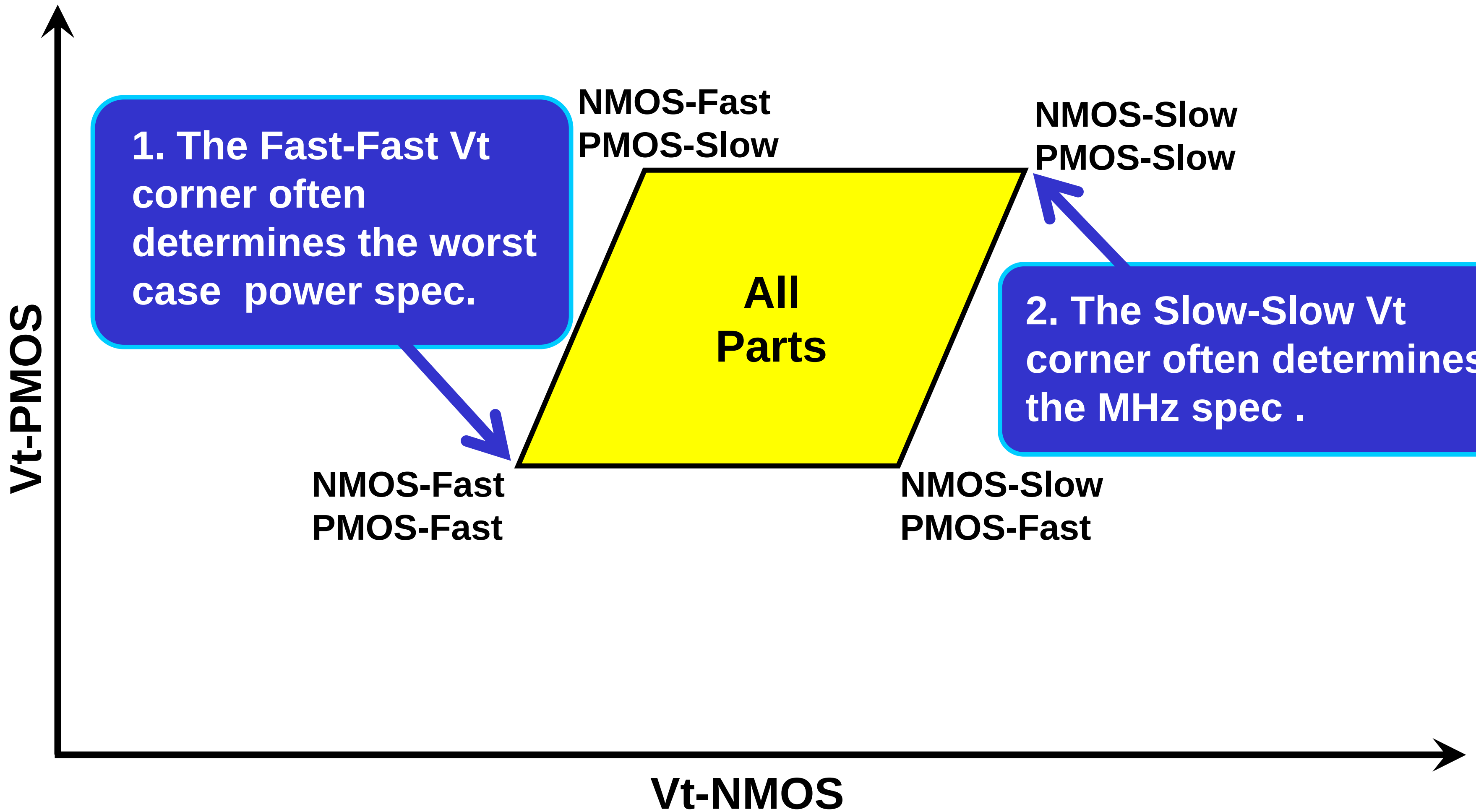
Unfortunately, as process variations grow, this scheme produces inferior results…

Now, it's all about the "Distribution"

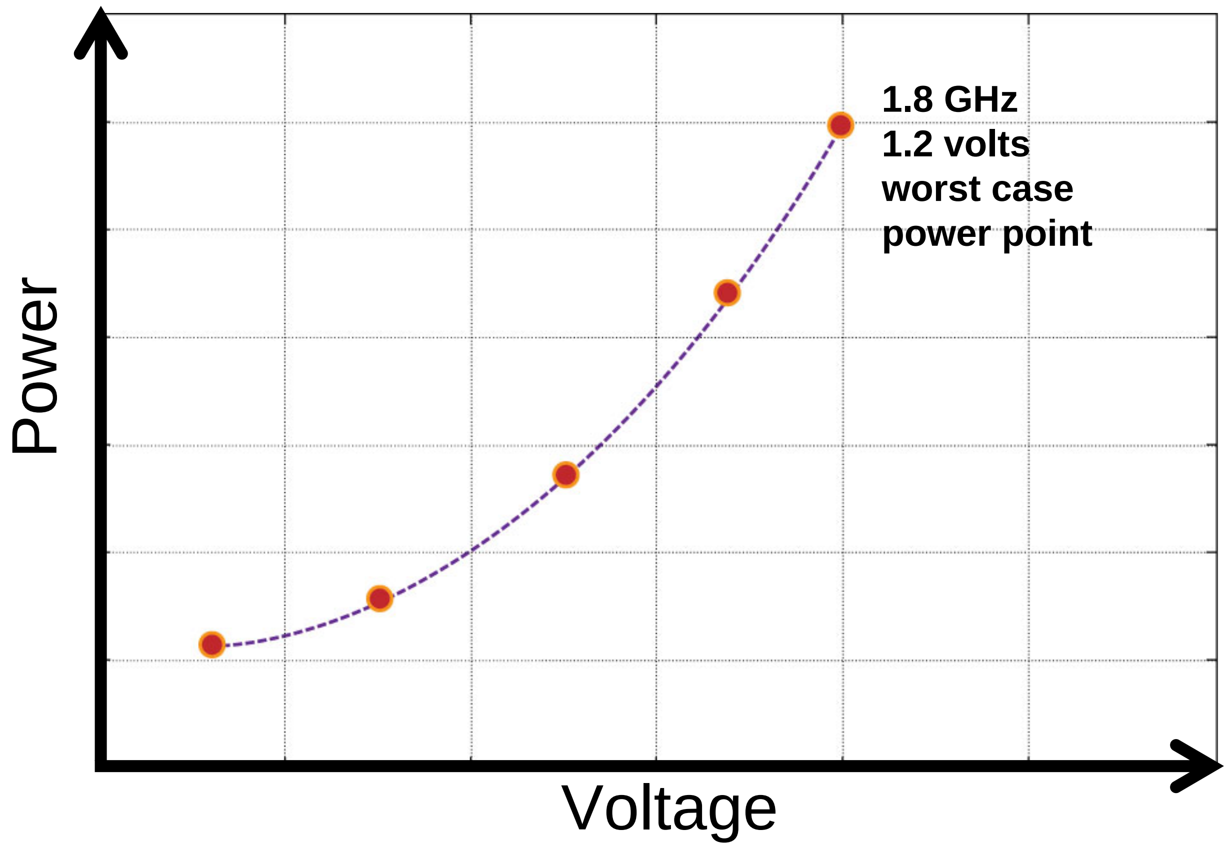


Distribution Corners Determine Chip Specs

"The SPICE box"



LongRun – Dynamic MHz/Voltage Scaling

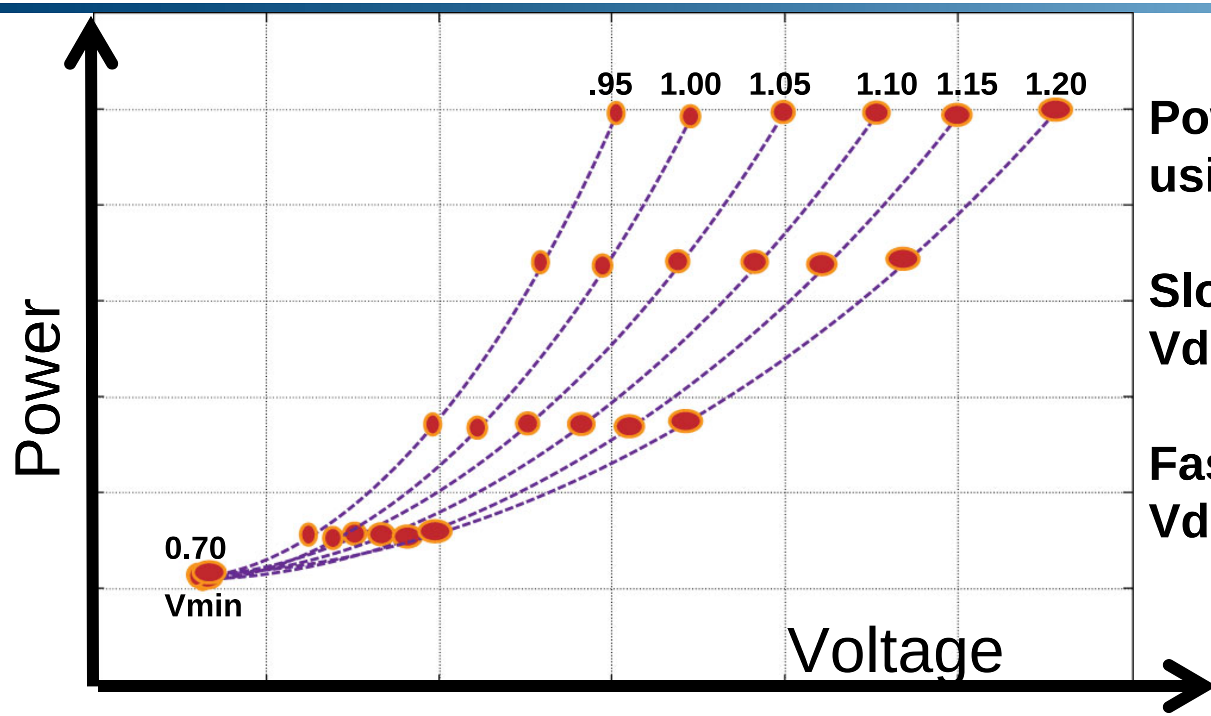


Example LongRun Table

GHz	Vdd
1.8	1.20
1.6	1.05
1.4	0.95
1.2	0.85
1.0	0.80

Reduces average power, but not worst-case power

Enhanced LongRun: Adding multiple Voltage IDs



Power can be reduced by using multiple top Vdd points.

Slow parts can use a higher Vdd, they have less leakage.

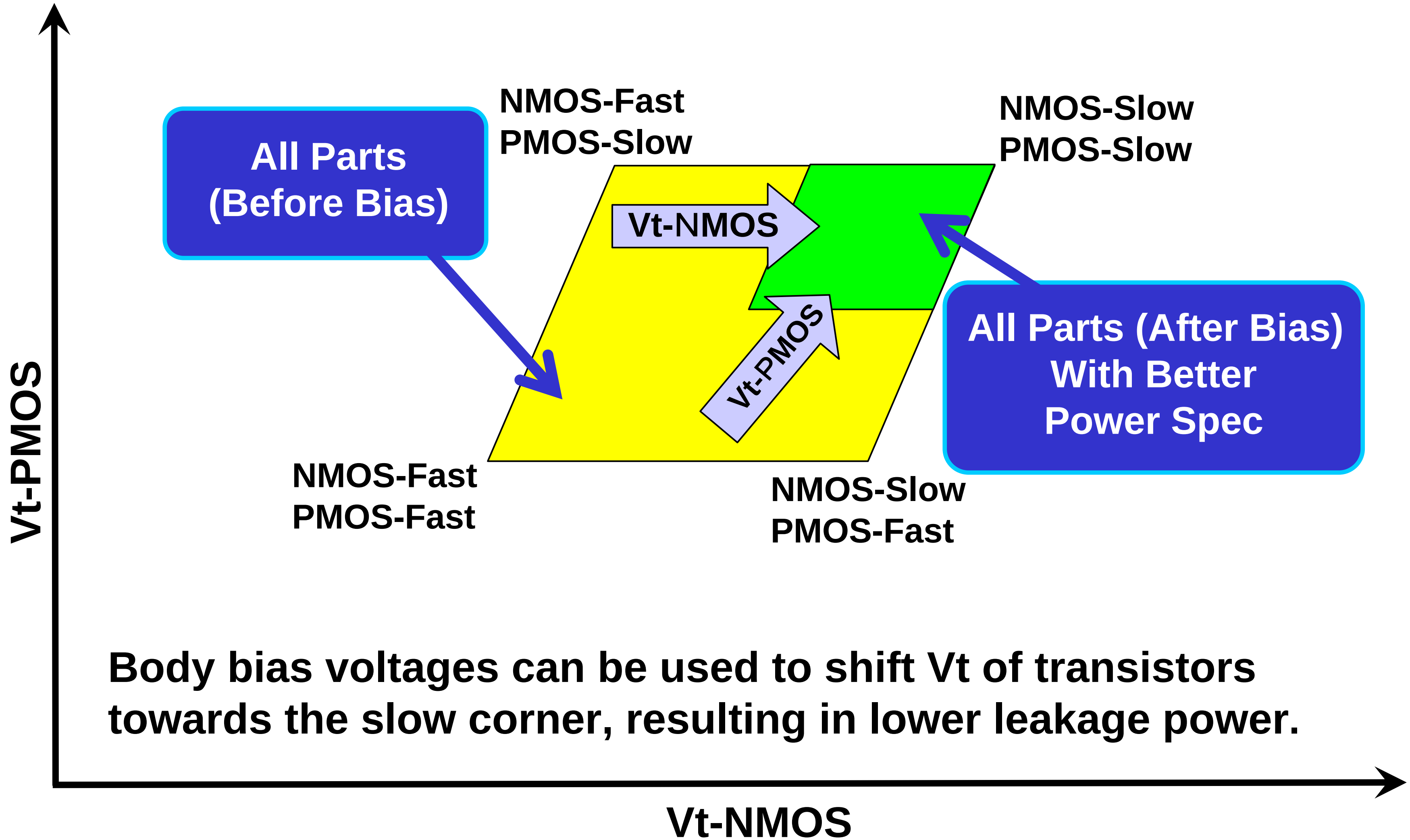
Fast parts can use a lower Vdd, they have more leakage

Adding Voltage ID to LongRun reduces power, but increases the number of tables.

6 LongRun Tables

GHz	Vdd	GHz	Vdd	GHz	Vdd	GHz	Vdd	GHz	Vdd	GHz	Vdd
1.8	1.20	1.8	1.15	1.8	1.10	1.8	1.05	1.8	1.00	1.8	0.95
1.6	1.05	1.4	1.00	1.4	0.95	1.4	0.90	1.4	0.85	1.4	0.85
1.4	0.95	1.2	0.90	1.2	0.85	1.2	0.80	1.2	0.75	1.2	0.75
1.2	0.85	1.0	0.80	1.0	0.75	1.0	0.70	1.0	0.70	1.0	0.70
1.0	0.80	1.0	0.75	1.0	0.70	1.0	0.70	1.0	0.70	1.0	0.70

Reduced Power with LongRun2 Vt Control

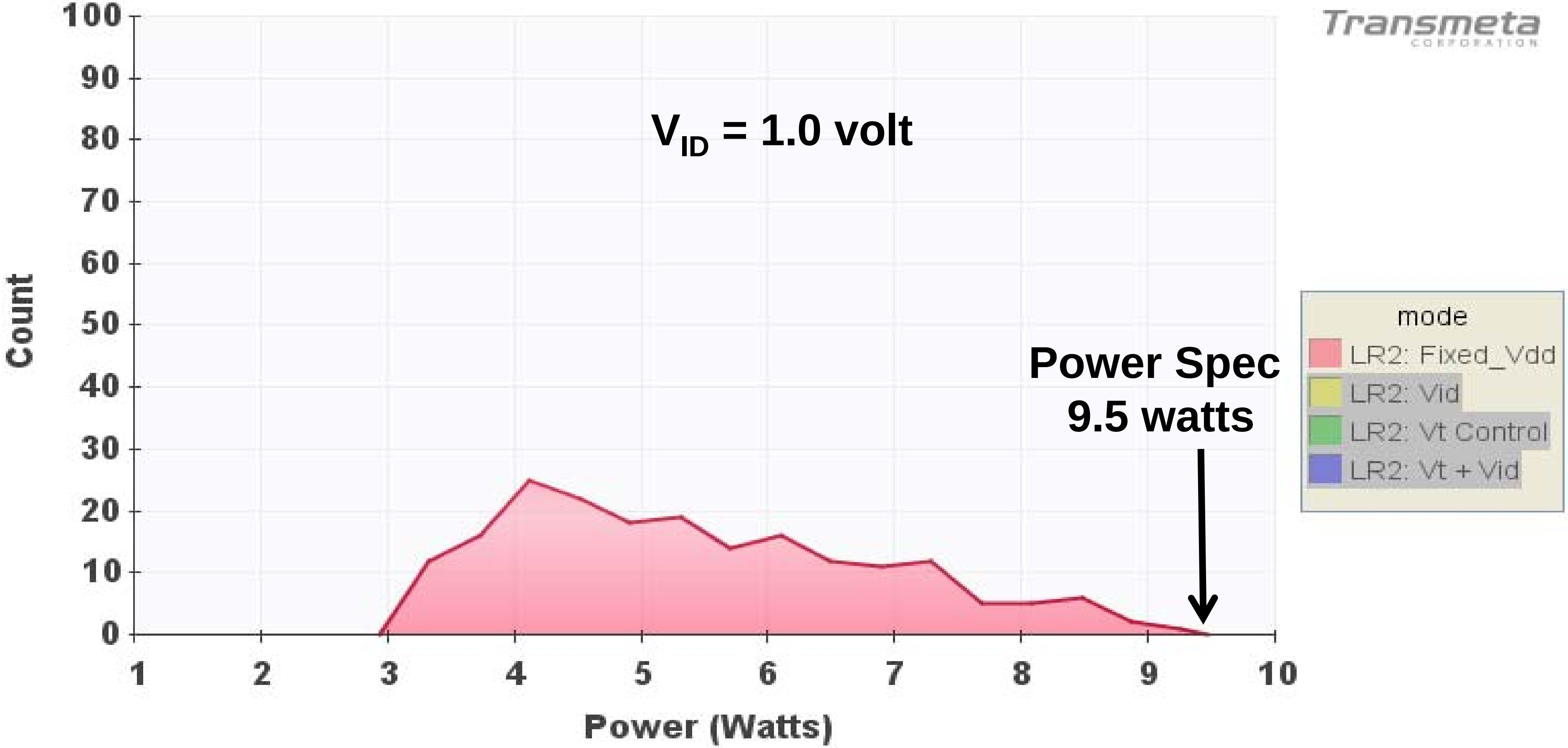


Body bias voltages can be used to shift Vt of transistors towards the slow corner, resulting in lower leakage power.

Study 1:

What is the Power if 1.5 GHz operation is needed?

1.5 GHz Fixed Vdd



mode	count	min	mean	median	max	stdev
LR2: Fixed_Vdd	196	3.14	5.44	5.18	9.46	1.45
LR2: Vid	196	2.79	3.91	3.74	6.52	0.68
LR2: Vt Control	202	2.52	3.06	3.02	3.98	0.31
LR2: Vt + Vid	202	1.95	2.86	2.85	3.62	0.29

Target: Frequency = 1.5 GHz

1.5 GHz with Voltage ID

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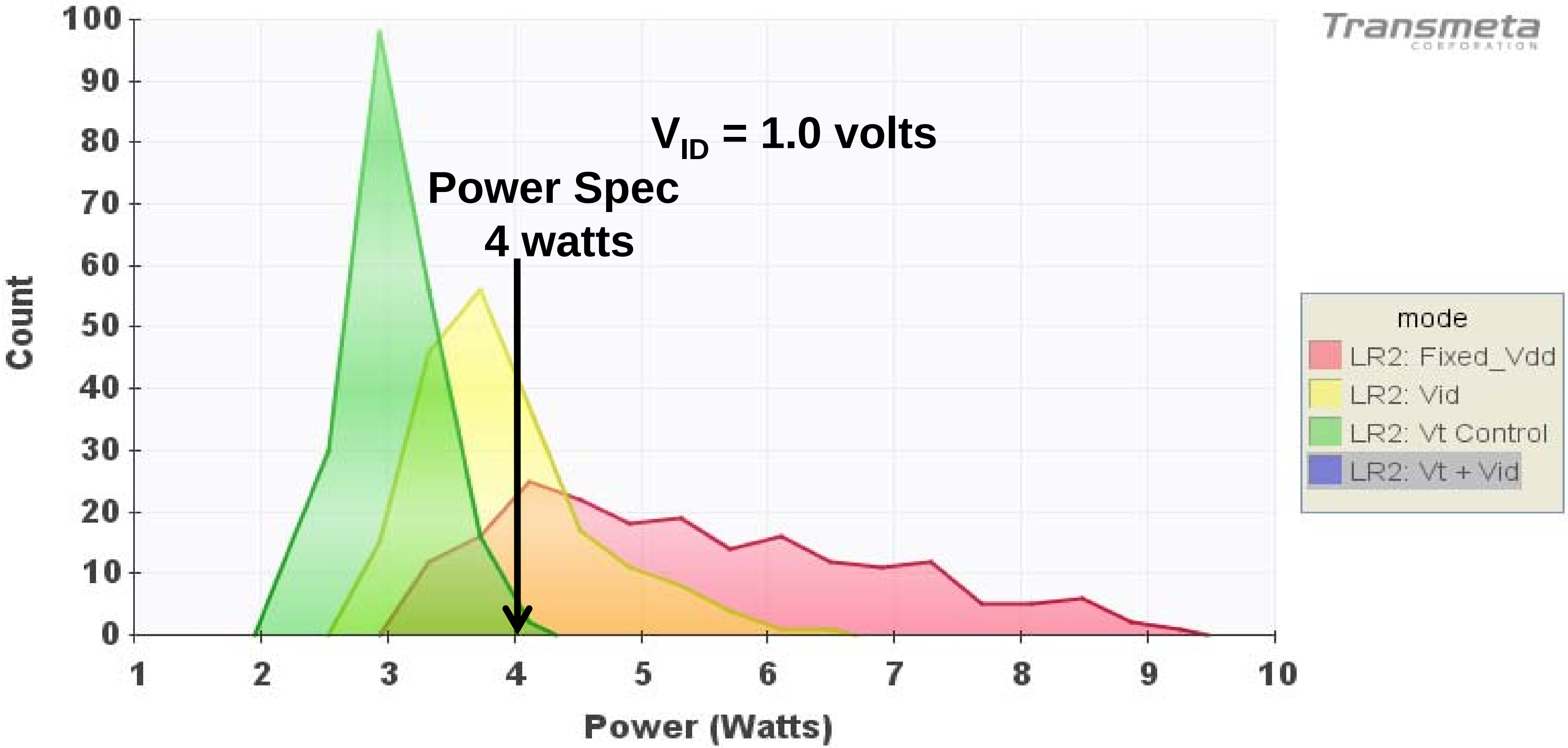
1.5 GHz with Vt Control and Fixed Voltage



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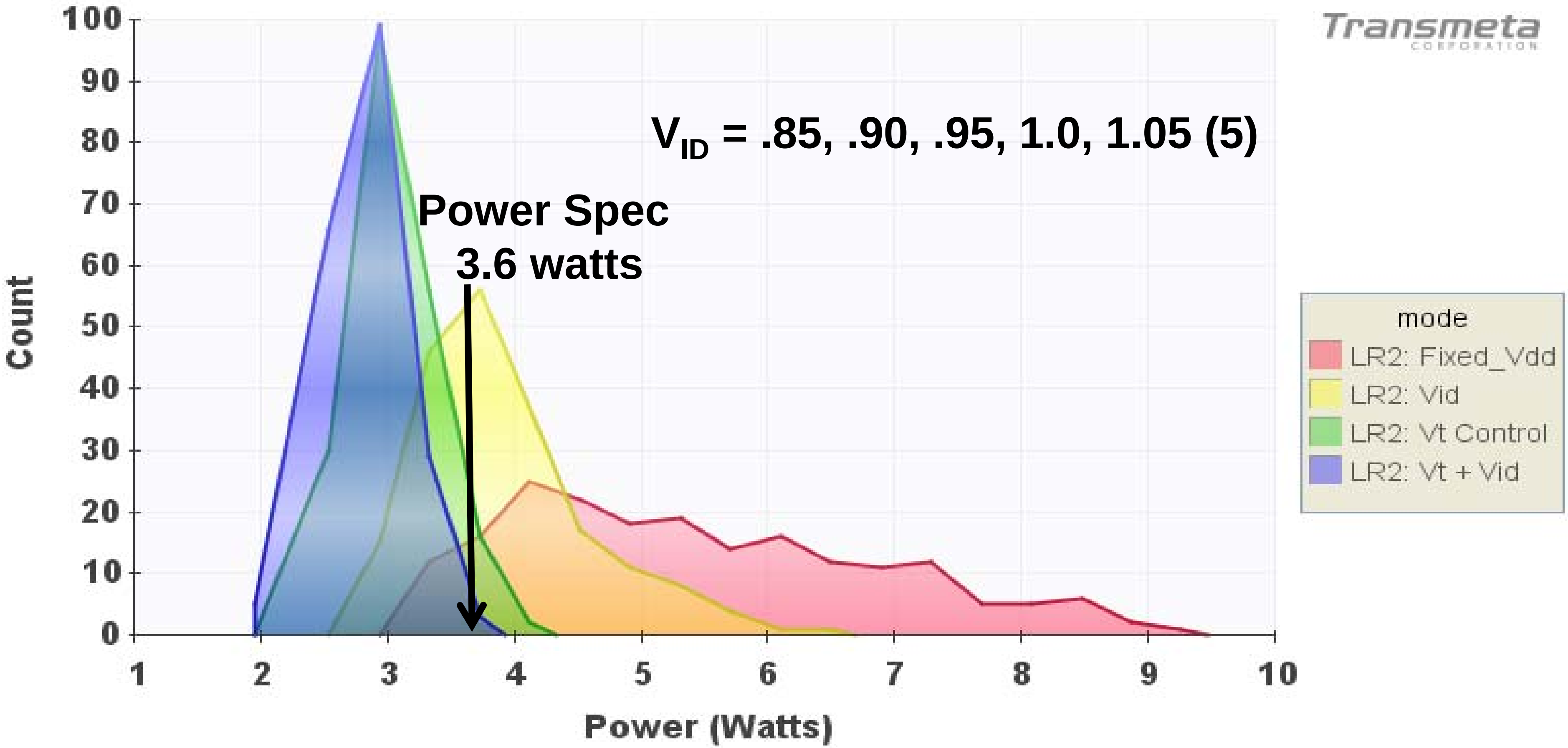
1.5 GHz with Vt Control and Voltage ID



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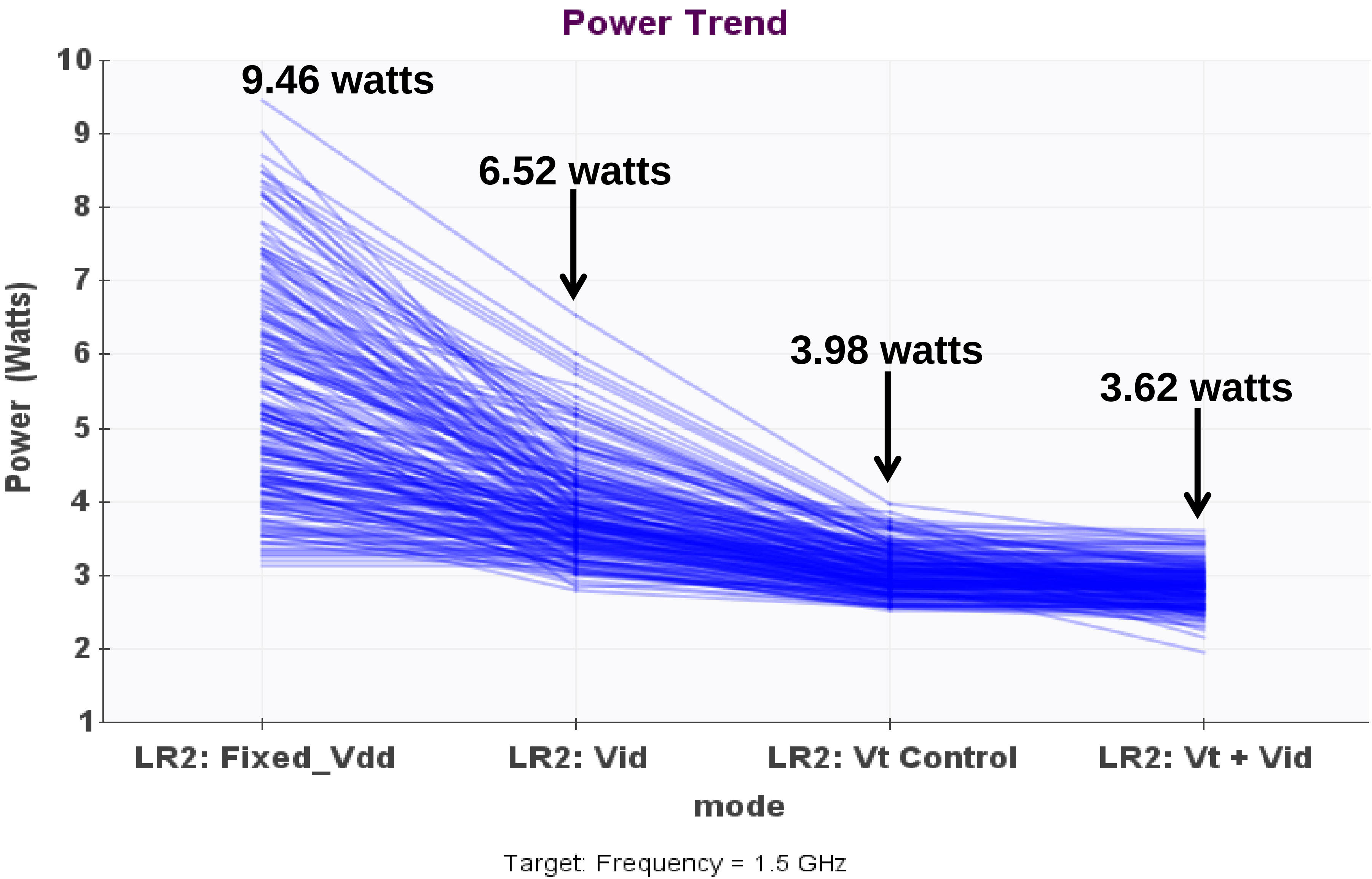
1.5 GHz Power reduction across distribution



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1.5 GHz Summary

Scheme	1.5 GHz Power Spec	Relative Power Reduction
LongRun2 Fixed Vdd	9.46 watts	1.0x
LongRun2 Voltage ID	6.52 watts	1.5x
LongRun2 Vt Control with Fixed Vdd	3.98 watts	2.4x
LongRun2 Vt Control with Voltage ID	3.62 watts	2.6x

2.6x Reduction in Power

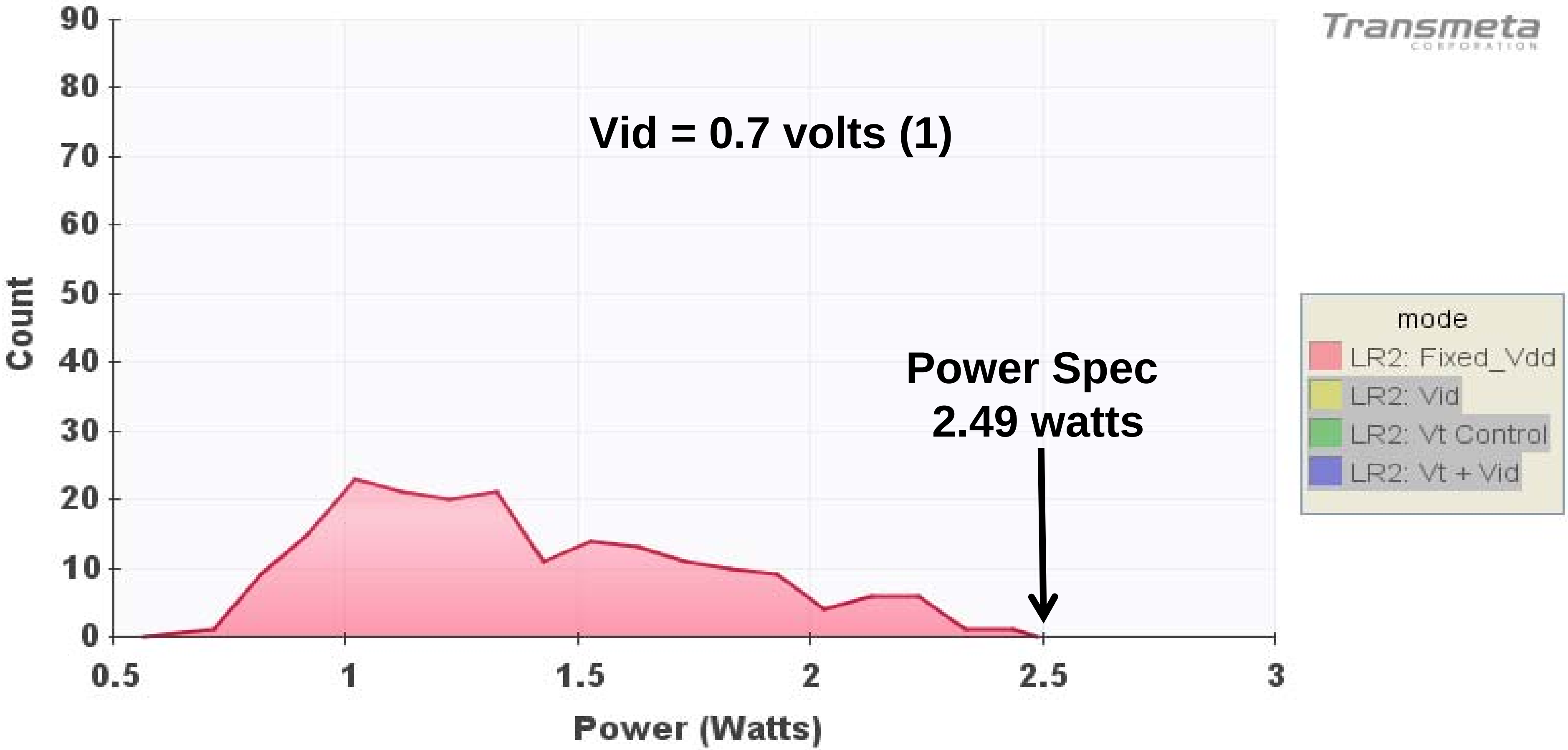
with LongRun2 Vt Control and Voltage ID

Note: Customers may be reluctant to use Voltage ID if it requires testing at each Vid and increased power supply costs, in which case LongRun2 Vt Control with Fixed Vdd provides an attractive alternative.

Study 2:

What is the Power if 700 MHz operation is needed?

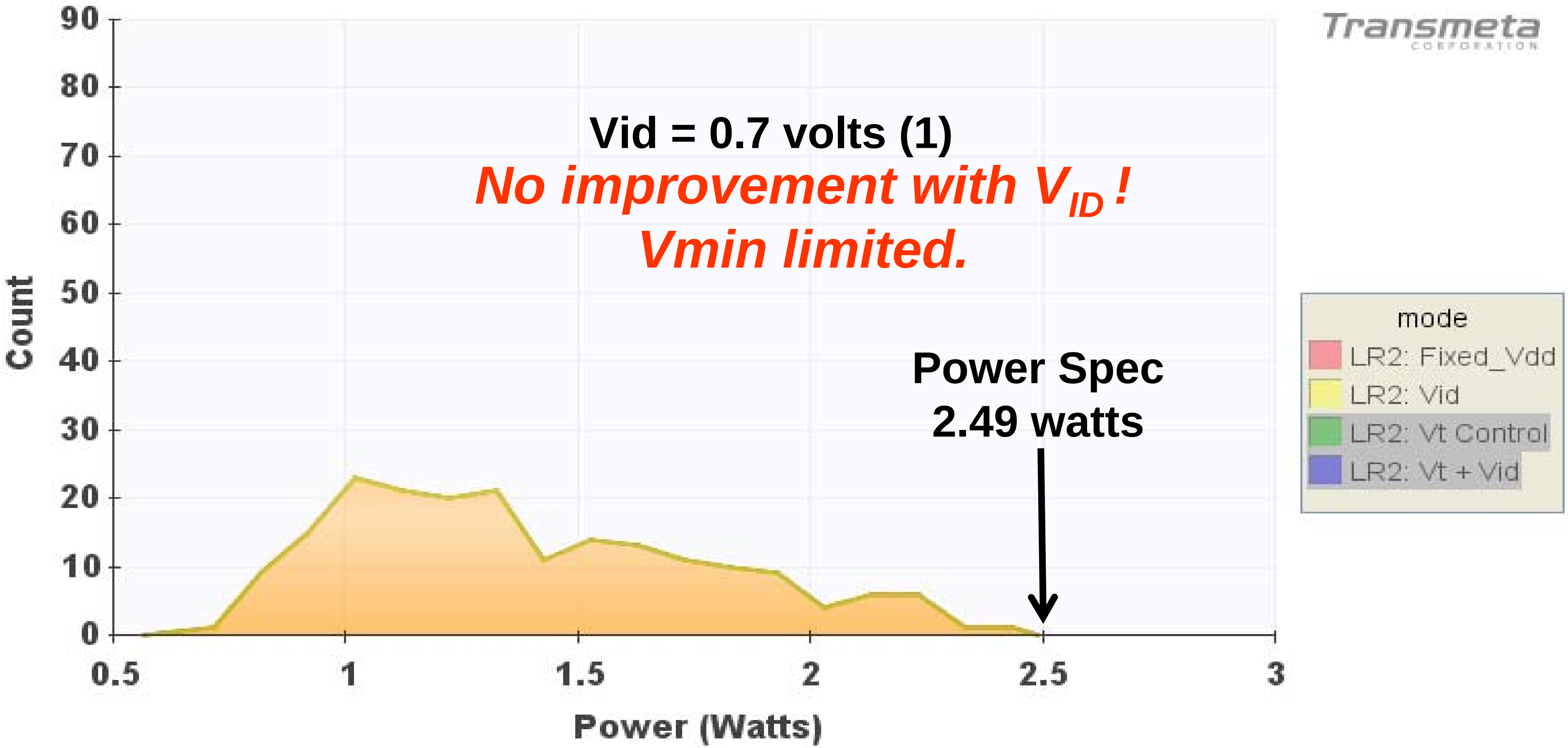
700 MHz with Fixed Voltage



mode	count	min	mean	median	max	stdev
LR2: Fixed_Vdd	196	0.77	1.39	1.32	2.49	0.39
LR2: Vid	196	0.77	1.39	1.32	2.49	0.39
LR2: Vt Control	202	0.56	0.71	0.68	1	0.1
LR2: Vt + Vid	202	0.56	0.71	0.68	1	0.1

Target: Frequency = 0.7 GHz

700 MHz with Voltage ID



Target: Frequency = 0.7 GHz

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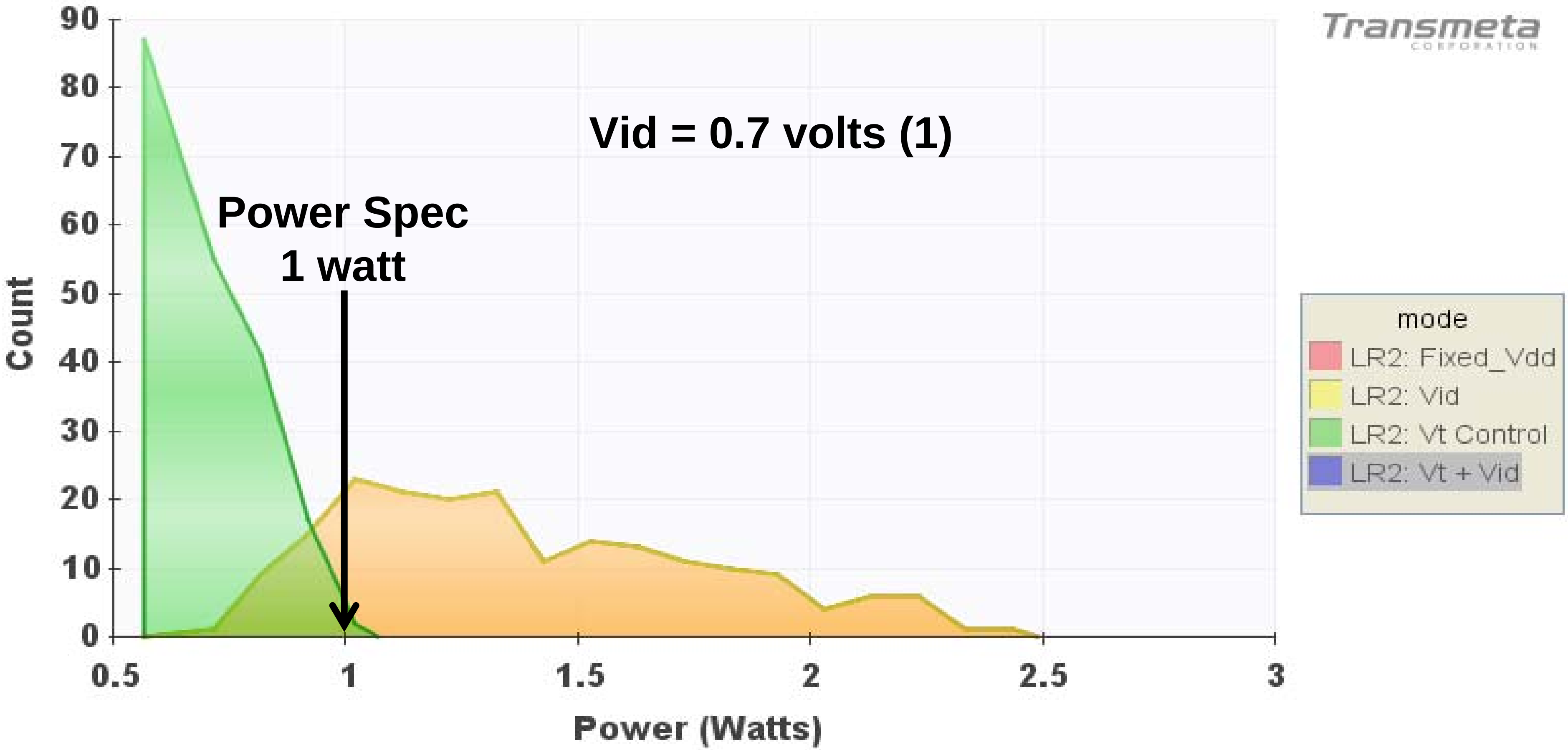
Vmin is the lowest Vdd voltage at which device is functional

700 MHz with Vt Control and Fixed Voltage



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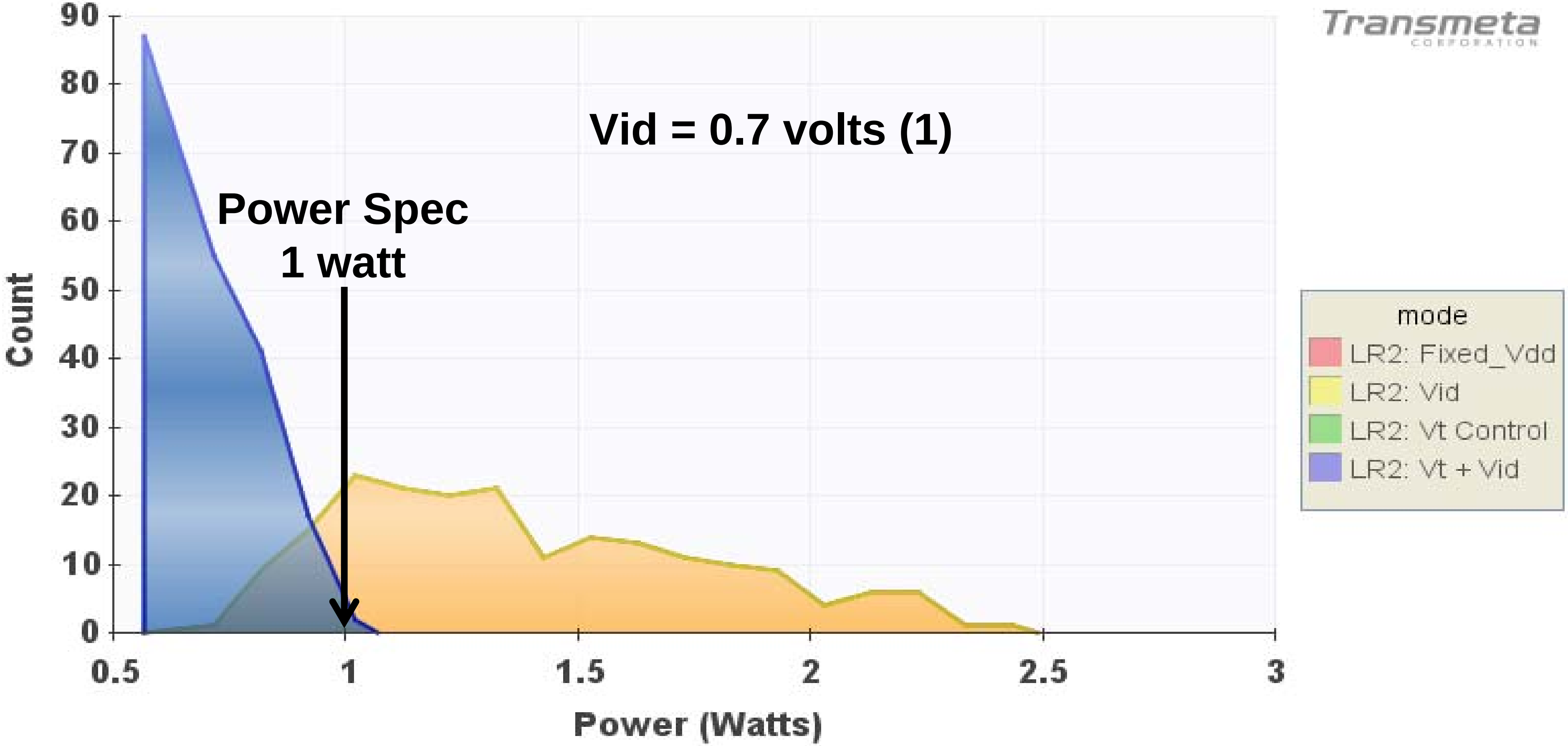
Target: Frequency = 0.7 GHz

700 MHz with Vt Control and Voltage ID



Target: Frequency = 0.7 GHz

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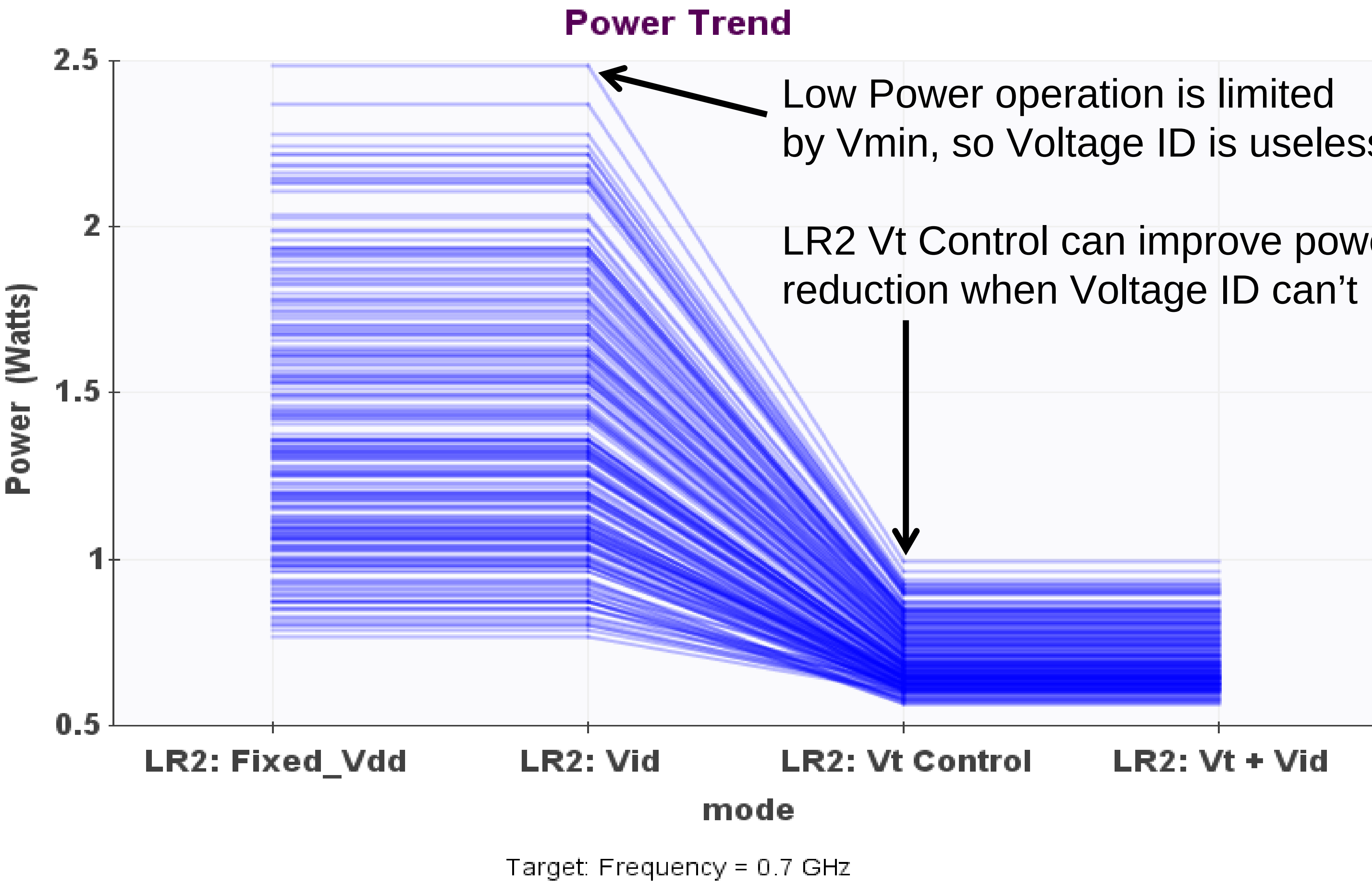
700 MHz Power reduction across distribution



Low Power operation is limited by Vmin, so Voltage ID is useless

LR2 Vt Control can improve power reduction when Voltage ID can't

700 MHz Summary

Scheme	700 MHz Power	Relative Power Reduction
LongRun2 Fixed Voltage	2.49 watts	1.0x
LongRun2 Voltage-ID	2.49 watts	1.0x
LongRun2 Vt Control with Fixed Voltage	1.00 watts	2.5x
LongRun2 Vt Control with Voltage-ID	1.00 watts	2.5x

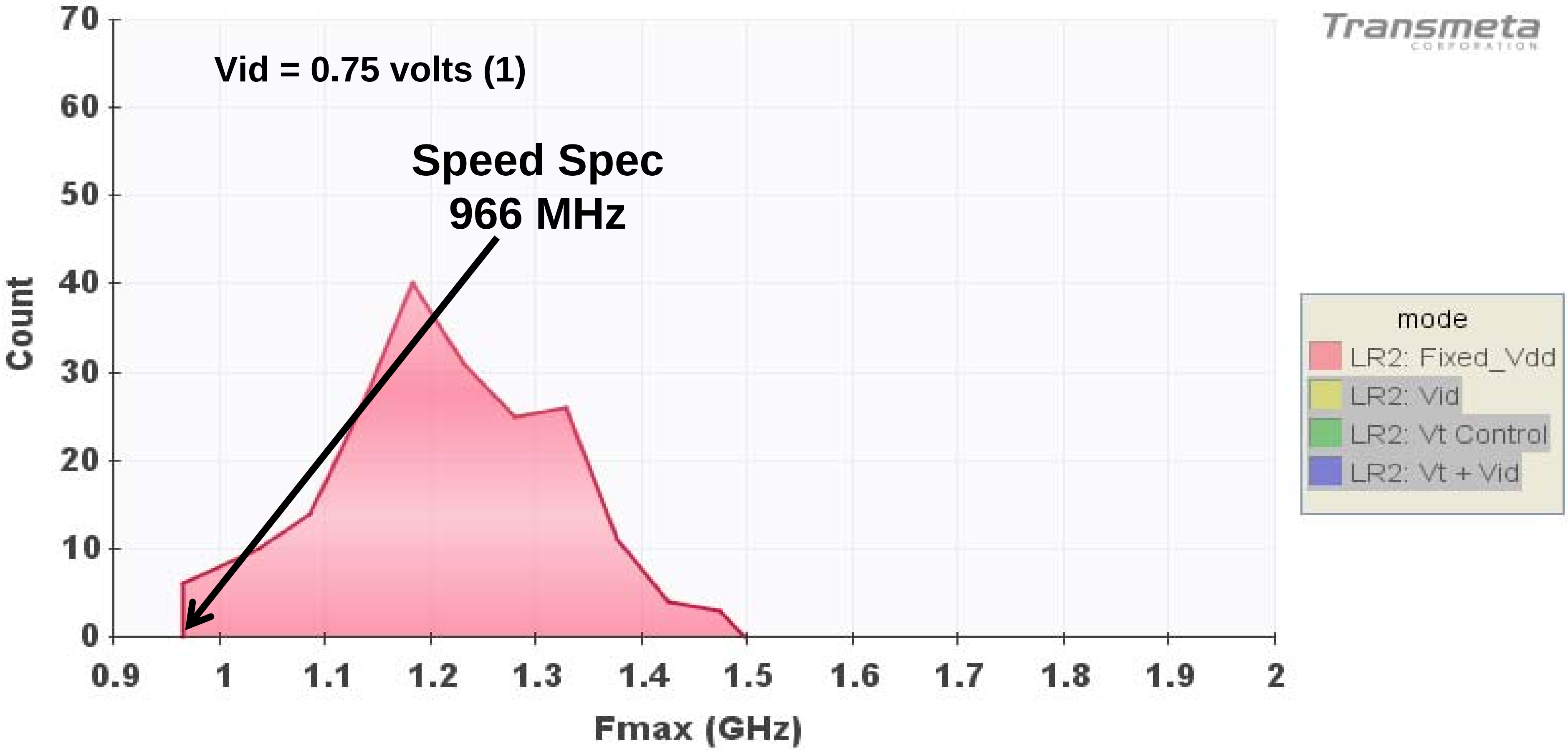
2.5x reduction in power
with LongRun2 Vt Control

LongRun2 Vt Control reduces power when Voltage ID can not because of Vmin restrictions

Study 3:

What MHz can be reached if less that 4 watts is needed?

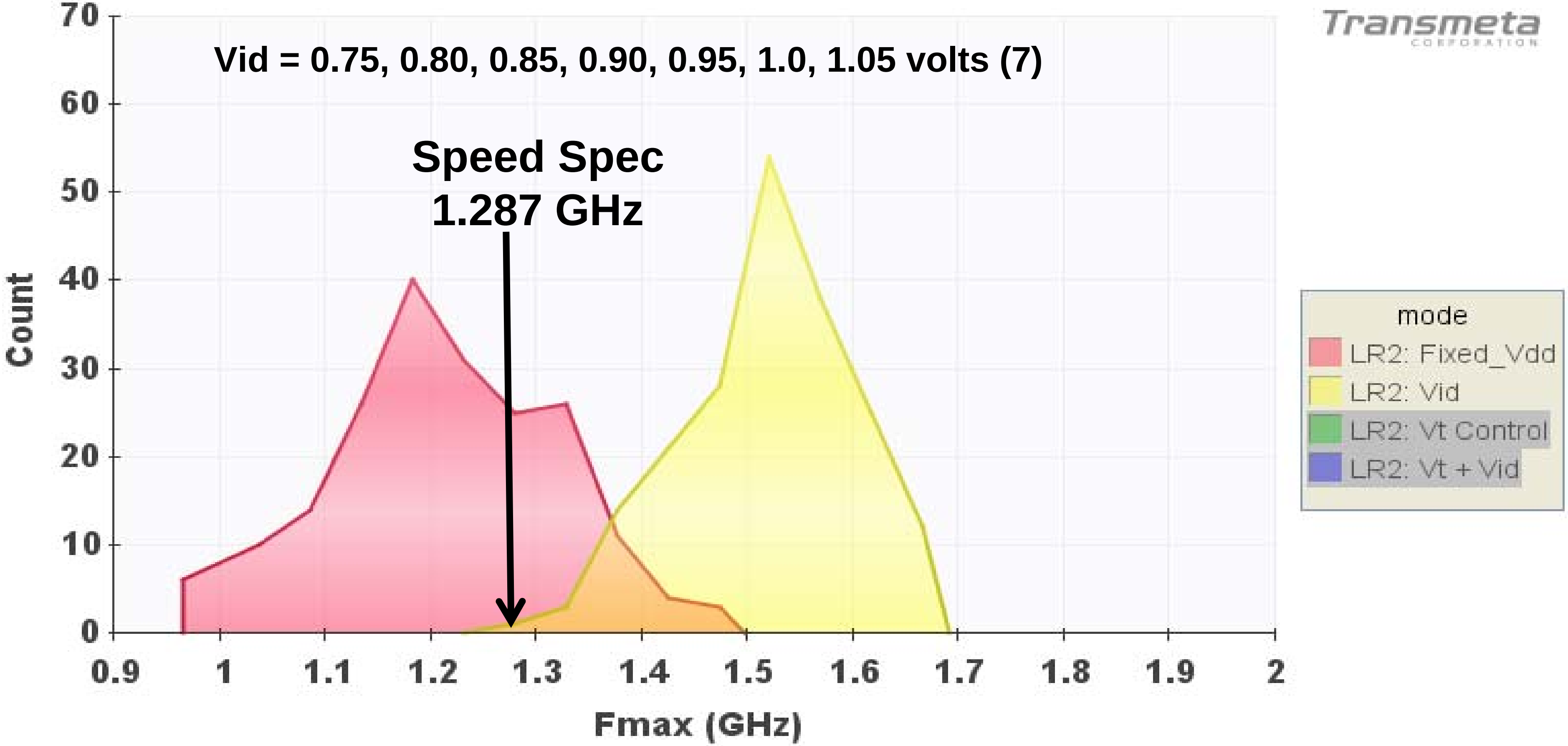
4 Watt Power with Fixed Voltage



Target: Power <= 4 Watts

mode	count	min	mean	median	max	stdev
LR2: Fixed_Vdd	196	0.966	1.215	1.215	1.472	0.104
LR2: Vid	196	1.287	1.522	1.526	1.677	0.079
LR2: Vt Control	202	1.513	1.641	1.632	1.831	0.06
LR2: Vt + Vid	202	1.554	1.687	1.687	1.884	0.056

4 Watt Power with Voltage ID



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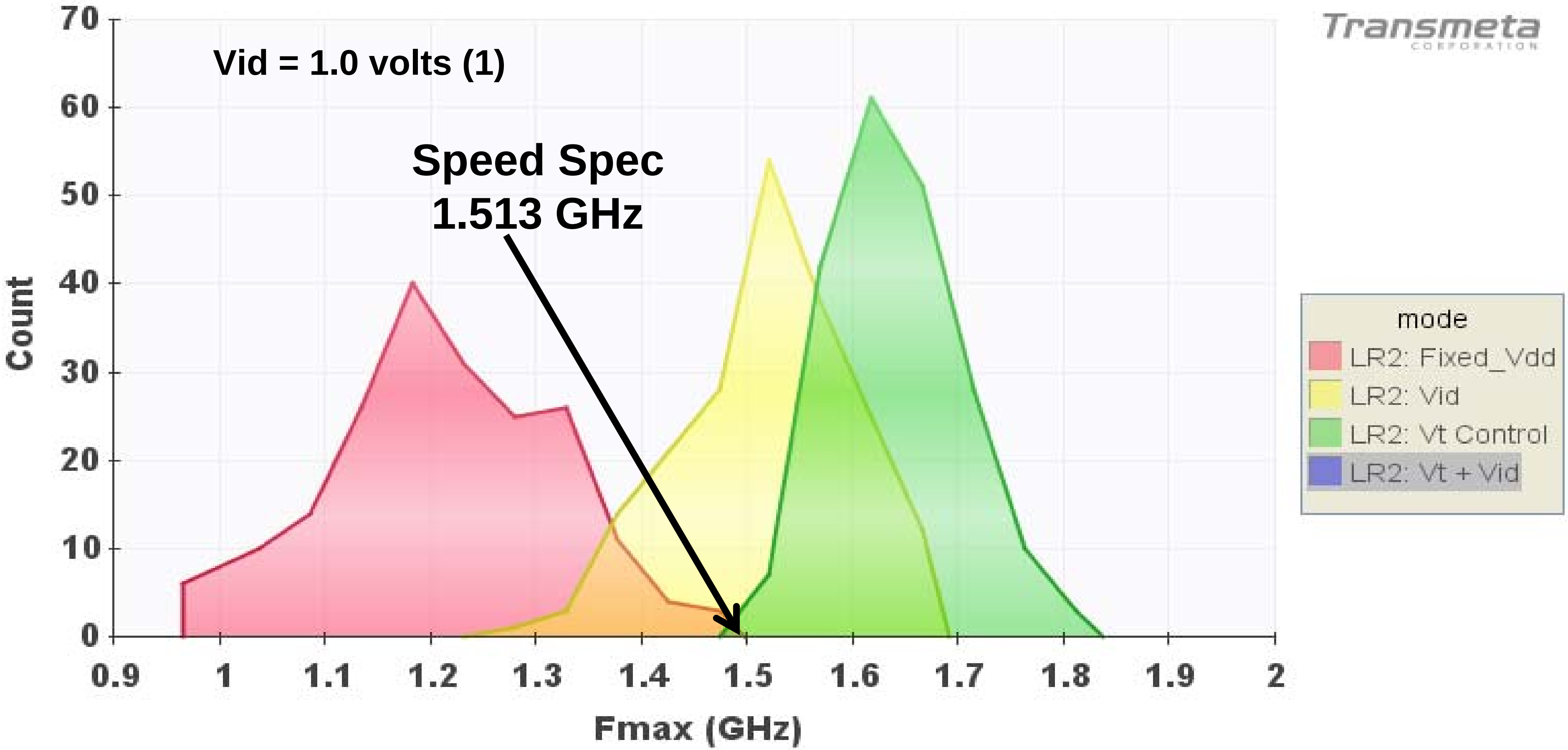
4 Watt Power with Vt Control and Fixed Voltage



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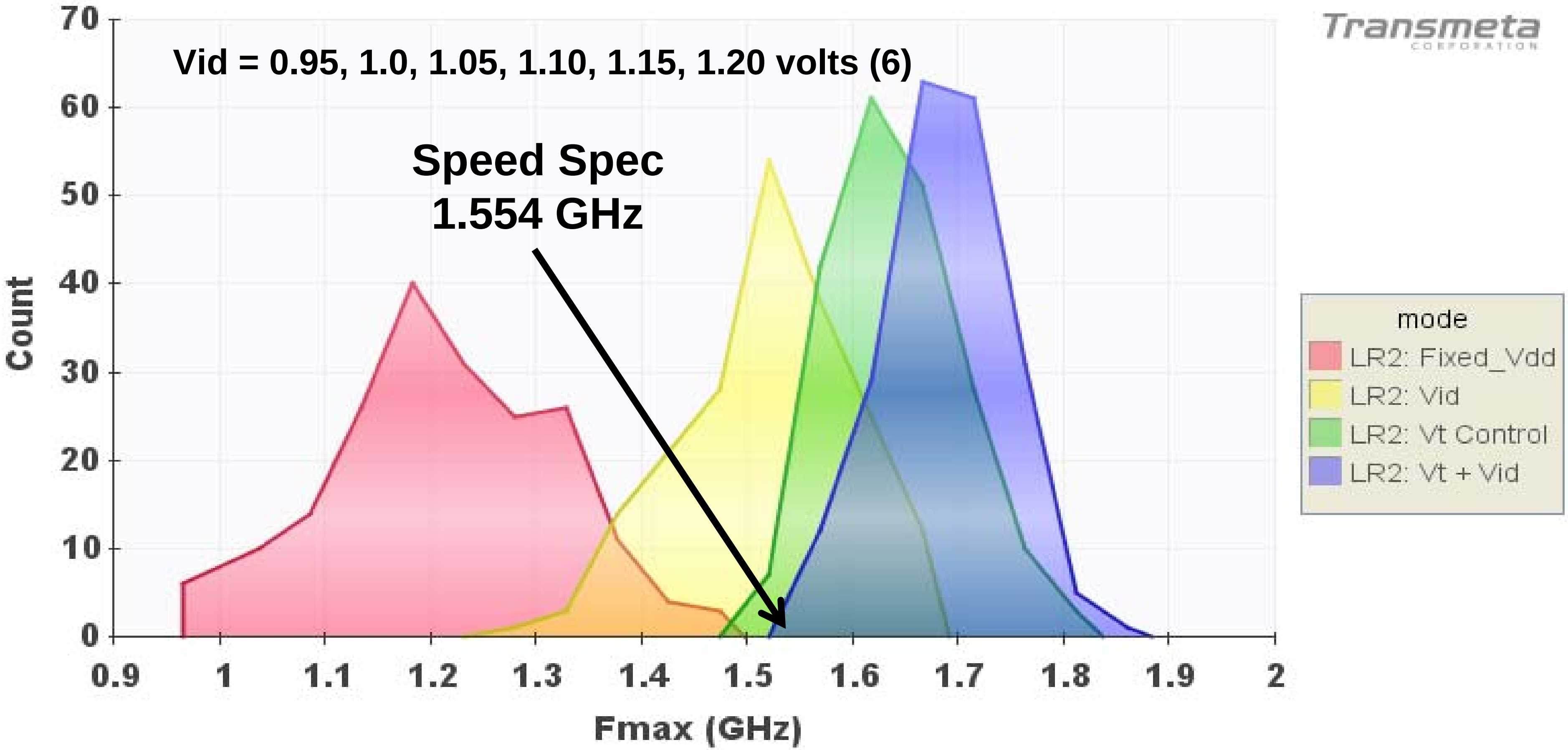
4 Watt Power with Vt Control and Voltage ID



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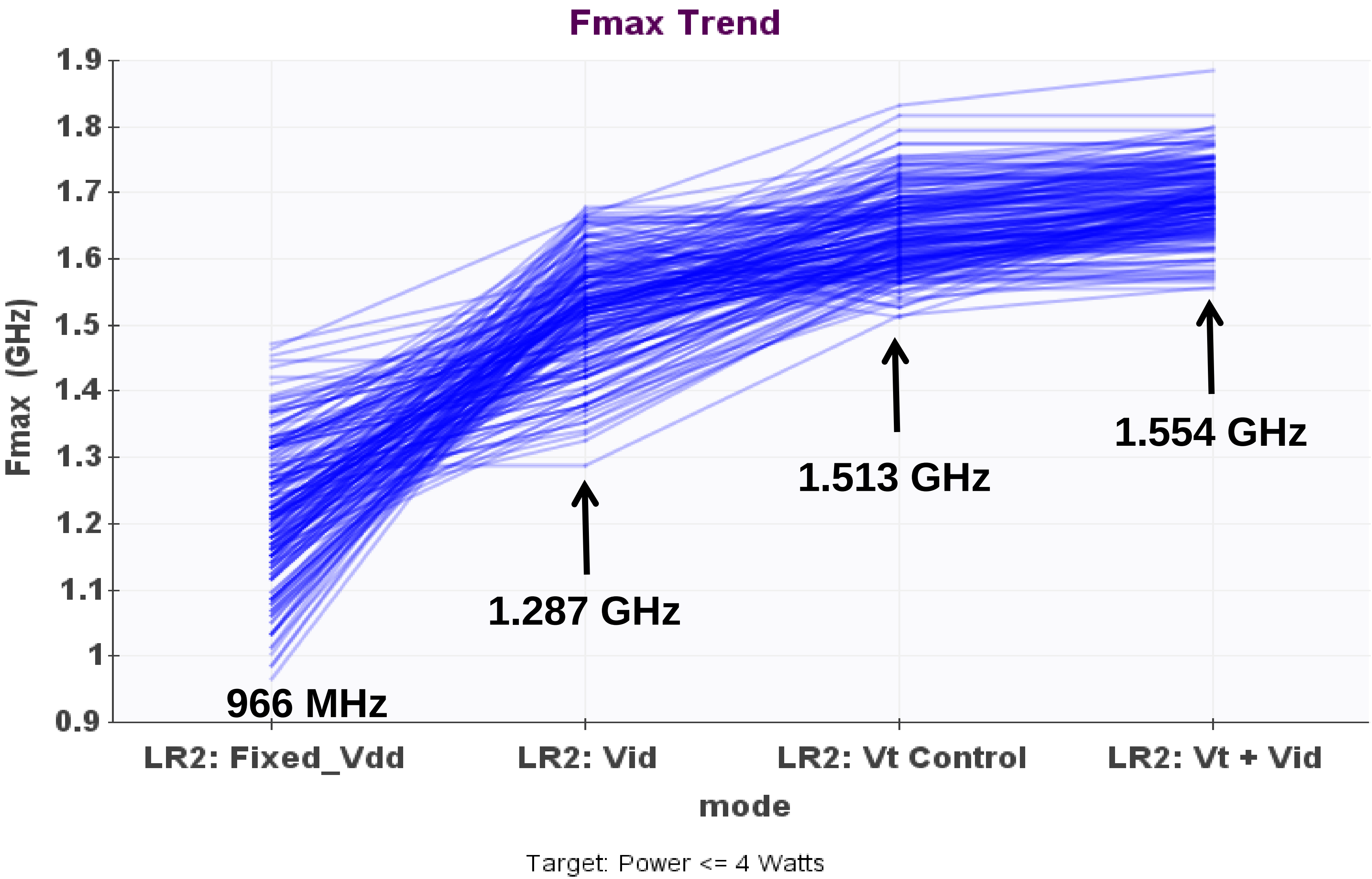
Target: Power <= 4 Watts

4 Watt Power: Frequency Improvement



4-Watt Power Summary

Scheme	MHz Specification	Relative MHz Increase
LongRun2 Fixed Voltage	966 MHz	1.0x
LongRun2 Voltage ID	1.287 GHz	1.3x
LongRun2 Vt Control with Fixed Voltage	1.513 GHz	1.6x
LongRun2 Vt Control with Voltage ID	1.554 GHz	1.6x

1.6x increase in MHz with LongRun2 Vt Control

Conclusion

LongRun2 Technologies provides a set of solutions to help reduce variation across a distribution of parts, which can

- Improve the power spec
- Improve the MHz spec
- Improve yield and reduce costs

LongRun2 enabled 90nm Efficeon to

- Reduce the power spec by 2.5x
- Increase the MHz spec by 1.6x
- Operate at 700 MHz at < 1 watt
- Operate at 1.5 GHz at < 3.6 watts

In addition to improving static worst case specs, LongRun2 can also be used to reduce standby power, reduce average power under dynamic MHz/Vdd operation and adjust for other runtime factors such as temperature and power supply variation.

- Toshiba, SONY, Fujitsu and NEC are licensed LongRun2 fabs

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